Software Engineering Institute
Carnegie Mellon University

IEEE Computer Society/Software Engineering Institute Watts S. Humphrey Software Process Achievement Award 2016: Raytheon Integrated Defense Systems Design for Six Sigma Team

Neal Mackertich
Peter Kraus
Kurt Mittelstaedt
Brian Foley
Dan Bardsley
Kelli Grimes
Mike Nolan

April 2017

TECHNICAL REPORT
CMU/SEI-2017-TR-001

Software Solutions Division

http://www.sei.cmu.edu

The Software Engineering Institute is funded and supported by the Department of Defense under Contract No. FA8702-15-D-0002 with Carnegie Mellon University.

DM17-0040

Table of Contents

List of Figures

List of Tables

About Raytheon Integrated Defense Systems

Raytheon Company is a technology and innovation leader specializing in defense, civil, government, and cybersecurity solutions. Founded in 1922, Raytheon provides state-of-the-art electronics, mission systems integration, capabilities in command, control, communications, computing, cyber and intelligence (C5I), sensing, effects, and mission support services. Raytheon is headquartered in Waltham, Massachusetts.

Raytheon at a glance:

- Chairman and Chief Executive Officer: Tom Kennedy
- 61,000 employees worldwide
- $23 billion in sales for 2015

Raytheon Integrated Defense Systems (IDS) is one of five businesses within Raytheon Company and is headquartered in Tewksbury, Massachusetts. Raytheon IDS specializes in air and missile defense, large land- and sea-based radars, and systems for managing C5I, surveillance, and reconnaissance. It also produces sonars, torpedoes, and electronic systems for ships.

Raytheon IDS capabilities include

- missile defense
- command and controls
- sensors and imaging
- electronic warfare
- precision weapons

Abstract

Design for Six Sigma (DFSS) is an industry recognized methodology used by Raytheon's Integrated Product Development System to predict, manage, and improve software-intensive system performance, producibility, and affordability. The Raytheon Integrated Defense Systems DFSS team has developed and implemented numerous leading-edge improvement and optimization methodologies resulting in significant business results. These achievements have been recognized by the Software Engineering Institute and the Institute of Electrical and Electronics Engineers with the 2016 Watts Humphrey Software Process Achievement Award. Best practice approaches used by the team are shared in this report, including the generation of highly effective and efficient test cases using Design of Experiments, process performance modeling and analysis, and cost and schedule risk analysis using Monte Carlo simulation.

1 Enabling Improved Software Systems Performance through Design for Six Sigma (DFSS)

1.1 The Software Systems Engineering Challenge

Whether we practice software systems engineering in the aerospace, commercial, automotive, or service-oriented industries, the game we play is the same: develop increasingly complex systems with smaller performance margins that meet the users' requirements in the shortest time, with high reliability, while remaining open and adaptable, and at the lowest cost. As software systems engineers, we focus on the basics: define the requirements and architecture, develop the plan, design and analyze, and finally integrate, verify, and validate. We all know that these are the basics and you have to follow the standard process or you can't even be in the game. We have configuration management practices to assure that we manage changes along the way and perform contract modifications and negotiations with the customer throughout the lifecycle. Our customers understand the process and adhere to it.

However, we naturally want to push the boundaries of what is possible to be able to deliver capabilities to users in the least amount of time and at the lowest cost. Companies and software systems engineers that are good at managing their customers and providing data to support contract specification, schedule, and cost negotiations usually win the game. Yet with increasing complexities, increased emphasis on mission assurance, aggressive cost reduction targets, shorter time-to-market requirements, and ever-changing user needs, our developed systems must become increasingly robust to keep us ahead. Our processes, tools, training, and people must adapt just as quickly, if not quicker, than our competitors to customer and user demands. We need a set of proven enablers that we can insert into our existing product development process to address these challenges in our software systems environment.

1.2 Design for Six Sigma (DFSS)

In 2005, the Raytheon Integrated Defense Systems (IDS) engineering Design for Six Sigma (DFSS) team was formed to identify, develop, pilot, and deploy industry best practice product optimization methods and processes to predict, manage, and improve performance, producibility, and affordability for the benefit of our customers. DFSS is the proactive application of our overall Raytheon Six Sigma program, focused on product optimization. DFSS methodologies deployed within Raytheon's Integrated Product Development Process (IPDP) are proven enablers in the identification of critical customer requirements, development of architectures, optimization of critical design parameters, development and deployment of enabling process performance models, analysis of cost and schedule, and the successful integration, verification, and validation of our systems.

The Raytheon IDS DFSS program is defined as having the following technical elements:

- voice-of-the-customer analysis, enabling architecture/design trade-off evaluation
- up-front architecture/design trade space evaluation

- performance modeling, integration, and analysis
- cost risk analysis using Monte Carlo simulation
- focused application of Design for Manufacture and Assembly (DFMA) with sustainment principles and practices
- statistical test optimization (STO) using Design of Experiments (DOE)
- critical chain project management; schedule risk assessment and critical chain for execution (RAACE) concepts (including that of schedule risk analysis using Monte Carlo simulation)
- supplier partnering using DFSS methodologies

While each of these technical elements in their own right have delivered significant value to the Raytheon IDS business, the focus of this report will be on the development, piloting, and integrated deployment of three specific core DFSS methodologies that have most significantly impacted our abilities to predict, manage, and improve our software systems. These are described in Sections 2, 3, and 4.

1.3 Measures of Success and Delivered Results

Effective measures of success are integral for determining the degree of success in delivering results against business objectives. The DFSS team has developed and deployed an integrated scorecard using an Oregon Productivity Matrix (OPM) to measure success against established goals. A supporting project activities database was also developed to provide centralized tracking and management for all deployments and engagements related to DFSS.

Specific measures of success tracked by the DFSS OPM against established annual goals and stretch targets include: achieved financial savings, return on investment (ROI) ratio (financial savings/process investment) from DFSS projects, the number of DFSS projects, delivered DFSS course training hours, and the number of customer and supplier DFSS project deployments. DFSS goals are established annually in concert with senior IDS leadership to enable Raytheon IDS business goals. Established annual IDS goals are specifically delineated on not only the DFSS team human resources performance screens, but also on the individual human resource performance screens of the IDS vice president of engineering and all functional directors (including systems engineering, software engineering, electrical design, and mechanical engineering). The entire value stream is “all in” relative to the delivery of DFSS results against goals. Annual achieved savings from DFSS projects have consistently delivered an annual ROI ratio of over 20:1.

The supporting DFSS project activities database was created to

- track all DFSS technical element engagements within IDS
- track DFSS projects to closure
- provide a tracking and document repository for all related assets
- provide multiple users with access to track the progress of their engagements
- provide workflow management of in-progress engagements
- provide historical library engagements by program, supplier, business, department, sponsor, POC, and so forth
- capture all highlights associated with monthly progress to goals

- make it easy to generate metrics for leadership by technical element, achieved cost savings, business, supplier, year, cost, training, and so forth
- provide a means of researching and sharing lessons learned across DFSS projects

2 Statistical Test Optimization Using Design of Experiments and Combinatorial Design Methods

This report focuses on the development, piloting, and integrated deployment of three specific core DFSS methodologies that significantly impacted our ability to predict, manage, and improve our software systems. In this section, we explain the first methodology, the application of statistical test optimization (STO) using Design of Experiments (DOE) and combinatorial design methods.

2.1 Identification of Significant Improvement Opportunity

As an industry we are being challenged by our customers and the marketplace to develop and deliver increasingly complex systems with smaller performance margins that meet the users' requirements in the shortest time, with high reliability, an open and adaptable architecture, and at the lowest cost. Given this challenge, there is increased pressure on test activities to ensure that software intensive systems meet all requirements and expectations given limited test resources. Industry studies have estimated that test and its associated rework represent 30% – 50% of the total product development costs. Given this investment, test represents fertile ground for optimization.

Accordingly, large-scale efforts are underway at the Department of Defense (DoD) to create a paradigm shift away from test events that are driven by combat scenario test strategies and budget concerns to an approach that is scientific and statistically rigorous. A guidance document published by the DoD director of operational test and evaluation provides a specific request to "increase the use of both scientific and statistical methods in developing rigorous, defensible test plans in evaluating their results" [7]. This guideline document requires test programs to report evidence of well-designed experiments, including continuous response variables, descriptions of how test factors will be controlled during test, and the strategy for exploring the design space. Similar statistical test optimization efforts are being undertaken in the commercial marketplace.

2.2 Methodology Development

Traditionally, DOE techniques have been used to model and optimize performance through the statistical identification and optimization of input factors and interactions that are statistically driving performance and variability. An industry opportunity emerged focused on extending the leverage of DOE within the test space with the motivation of integrating domain expertise and statistical methods to most effectively cover the test space at the minimum cost and cycle time.

The Defense Acquisition University glossary defines DOE as "a statistical methodology for planning, conducting, and analyzing a test/experiment." DOE allows testers to provide decision makers with statistically defensible options for testing that show how much it will cost to achieve a given level of knowledge. DOE enables a test planner to maximize the knowledge gained for a given set of resources through scientific planning processes. The purpose of a designed test or experiment is to ensure that the ranges of the causal variables are adequately covered to provide the most accurate responses possible for the fewest number of experiments and to answer the questions of interest while defining risks to support with statistically based decisions. Experimental

design methods are employed during test design planning such that the effect of factors (independent variables) and their interactions (synergistic effects) on one or more measured responses (also called dependent variables) can be statistically explored. After testing is completed and data collected, DOE analysis provides quantifiable statistically defensible conclusions about system performance.

DOE improves DoD test rigor by objectively justifying the number of trials conducted based on decision risk, well apportioning test conditions in the battle space, guiding the execution order to control nuisance variation, and objectively separating the signal of true system responses from underlying noise. DOE enables effectiveness of system discovery with detailed process decomposition, tying test objectives to performance measures, and it includes test matrices that span the operating region and allow for faults to be traced to causes. Efficiencies are gained by combining highly efficient screening designs with initial analyses to learn early, followed by knowledge-based test augmentation for continued learning via statistical modeling, culminating in validation tests—all with the purpose of full system understanding using only the resources necessary.

The menu of available modern designs is quite diverse, as are the statistical methods of linking input changes to associated output changes (analysis). Since the experimental units may be people, machines, techniques, services, and environmental effects—among others—DOE is a discipline that has applications across the full array of industrial, services, research, hard and social sciences, finance, scheduling, and engineering. The discipline was founded by Sir Ronald Fisher, a British mathematician and geneticist, in agricultural experimentation in the 1920s and 1930s. His seminal text, *The Design of Experiments*, was published in 1935. Experimental design grew into extensive use in the chemical and process industries in the 1950s, was adopted by Japan as they re-invented their industrial base in the 1960s, and saw increased use in industry as part of the quality movement in the 1970s and 80s. The modern period (circa 1990+), fueled by increasingly capable software tools, has seen worldwide employment of DOE in all industries and across the product lifecycle.

Table 1 lists some of the most common experimental designs [6]. The type of the design should always reflect the goal of the experiment. Several typical goals are captured in the table, including characterization, optimization, screening, and testing for problems.

Table 1: Common Defensible Experimental Designs, from International Test and Evaluation Association

Scientifically Defensible Designs

Older Design of Experiments Definition

Test Objectives	Example Design Method	Examples of Applications
Product design & development	Super-Saturated Designs	Trade Studies & Engineering Design and Analysis
	Factorial & Fractional Factorial Designs	
Process optimization	Response Surface Designs (RSM)	Trade Studies & Engineering Design and Analysis. Product design robust to manufacturing environ variations
	Optimal Designs	
Screen for important factors	Factorial & Fractional Factorial Designs	Characterizing Performance
Various, w/ hard-to-randomize factors (time/$$$/danger-to change)	Split/Strip Plot Designs	Mach-Alt Performance - Alt hard
	2nd Order Split Plot	Wind Tunnel Optimize - article cfig hard
Characterize a system or process over an envelope	Factorial & Fractional Factorial Designs, RSM, Optimal Designs, Covariates	Characterizing Performance with environmental variables; software performance testing over networks
Test for Problems	Combinatorial Designs (e.g. Factor Cover Array	Software Testing for faults
	Orthogonal Arrays	Integration & Interoperability
	Space Filling Designs	Integration & Interoperability
Evaluation of mat'l properties	Accelerated Life tests	Accelerated Life Tests
	Bayesian reliability	
	Mixture Designs	
Simple Cause-Effect Relations	Single Factor Regression RSM designs	Material properties, investigations, explorations
Item Acceptance Test	One sample t test	FQT, FCA, LA, surveillance, …
	Two sample t test	

In conjunction with DOE techniques, combinatorial design methods (CDM) are employed to statistically assess the test coverage of existing and under-development test plans. This is accomplished by determining the percentage of n-way combinations between identified input test parameters that are covered by potential alternative test plans. Specific interest is given to those n-way combinations that are of technical interest from a domain or use-case perspective. Once the key individual and interoperability requirements have been identified from a technical and use-case perspective, an optimized test plan is developed using DOE algorithms. The resulting developed experimental designs are mathematically orthogonal, thereby enabling root causal analysis.

2.3 Piloting, Measurement, and Refinement

Effective piloting, measurement, and refinement based on lessons learned from integrated program deployment are essential elements in process improvement. Therefore, the developed test

optimization using DOE methodology and associated process were piloted across a multiple set of diverse programs and test environments to maximize learning and refinement before full deployment. Expectations were clearly defined for the outcome prediction: a quantitative assessment of existing test coverage and the statistical generation of alternative, more efficient and effective test plans.

Table 2 summarizes the achieved pilot efficiencies that resulted from statistical test optimization efforts as compared with each of the individual original test plans [9]. In each case, these reductions were achieved while maintaining or improving upon existing test coverage. It should be noted that while the overall number of test cases in each case was reduced, there were observed subsections of testing (most notably within the system range testing) in which the number of individual tests was increased to achieve the desired level of test coverage.

Table 2: Achieved Efficiencies from integrated Statistical Test Optimization Using DOE Program Piloting

Test	Original Test Plan	Optimized Test Plan
Subsystem Scenario Testing	28 Tests	8 Tests (71% reduction)
Systems Mission Testing	25 Missions	18 Missions (28% reduction)
Software Simulation	100 Runs	40 Runs (60% reduction)
System Range Testing	1036 Tests	632 tests (39% reduction)
Software Subsystem Testing	90 Tests	63 Tests (30% reduction)
System Scenario Generation	8 Missions	6 Missions (25% reduction)
Software Verification Testing	1600 Tests	885 tests (45% reduction)
System Verification Testing	246 Tests	48 tests (80% reduction)

A more detailed walk-through of the process used in achieving these results is included as part of an unclassified case study in Section 2.5.

Specific refinements made to the developed methodology as a direct result of the piloting include the following: the development of an up-front, three-hour training course to enable stakeholder understanding of the methodology; the development of two in-parallel complementary processes (one for use when an existing test plan is present and one for use when a test plan is originated); and adjustments to the employed DOE nomenclature to enable quicker alignment with the terminology already in use by the various test teams.

2.4 Integrated Deployment, Validation, and Sustainment

Building on the piloting results and lessons learned, the DFSS team deployed the developed statistical test optimization using DOE process as an enabler integrated with Raytheon’s IPDP, and linked to specific test planning and execution process steps. The integration process requires detailed evidence that the developed process has been vetted through a robust piloting process or independent review. Because of this scrutiny, the process requires a significant degree of piloting evidence (note the piloting of this process across eight different projects and test environments), which typically serves us well. This case was no different with regard to new process validation and sustainment. Results from full integrated program deployment have been validated; an on-average reduction of 30% was achieved, while maintaining or improving on achieved test coverage

has resulted in significant business savings for our company and increased customer satisfaction. For process sustainment purposes, a number of sustainment assurances have been put in place, including capturing the financial benefits achieved by individual programs using STO in our DFSS database system, acquiring an unlimited license agreement for our primary toolset (the rdExpert Test Suite, a COTS tool suite provided by Phadke Associates), and the creation of an apprentice/mentor system for developing, maintaining, and expanding statistical test optimization using DOE subject matter expertise.

Raytheon senior leadership and our customers have become strong advocates of this development process. A quote from Raytheon CEO Dr. Tom Kennedy reinforces his advocacy: “There is no way around it – we have to find ways to do more with less. The integrated program use of statistical techniques such as DOE has proven itself to be a powerful enabler in our test optimization efforts to reduce cost and cycle time while providing our customers with confidence that our systems will perform.”

2.5 STO Case Study

The following high-level, unclassified electronic warfare (EW) subsystem case study provides a walk-through of statistical test optimization using DOE analysis process.

The list below describes the parameter design space as defined by the EW subsystem test team based on their invaluable domain expertise:

- platform type
  - missile, aircraft, ship, land
- frequency
  - band1, band2, band3 low, band3 high, band4
- frequency type
  - constant, agile
- PRI
  - CW, very low, low, medium, high
- PRI type
  - CW, constant, switcher, jitter, stagger
- PW
  - CW, narrow, medium, wide
- Scan
  - none, fast, medium, slow
- Scan type
  - steady, circular, conical, sector

Note that the parameter design space is defined based on an understanding of the subsystem requirements and operational needs.

Next we will define test constraints (test parameter combinations that are infeasible).

CW-related constraints

- PRI [CW] with PRI type [constant, switcher, jitter, or stagger]
- PRI type [CW] with PRI [very low, low, medium, or high]
- PW [CW] with PRI type [constant, switcher, jitter, or stagger]
- PW [CW] with PRI [very low, low, medium, or high]

Scan-related constraints

- scan [none] with scan type [circular, conical, or sector]
- scan type [steady] with scan [fast, medium, or slow]

Assessing the existing plan using combinatorial design methods (note that the original plan was developed using domain expertise solely without the use of DOE):

Original test plan

- 90 test cases

Existing coverage analysis results:

- critical domain (mains and 2-way) coverage: 84%
- overall domain (mains and 2-, 3-, 4-way) coverage: 54.6%
- 2-way combinations: 67.9%
- 3-way combinations: 35.2%
- 4-way combinations: 15.5%
- missing 2-way combinations: 144 (168 Total – 24 constraints)

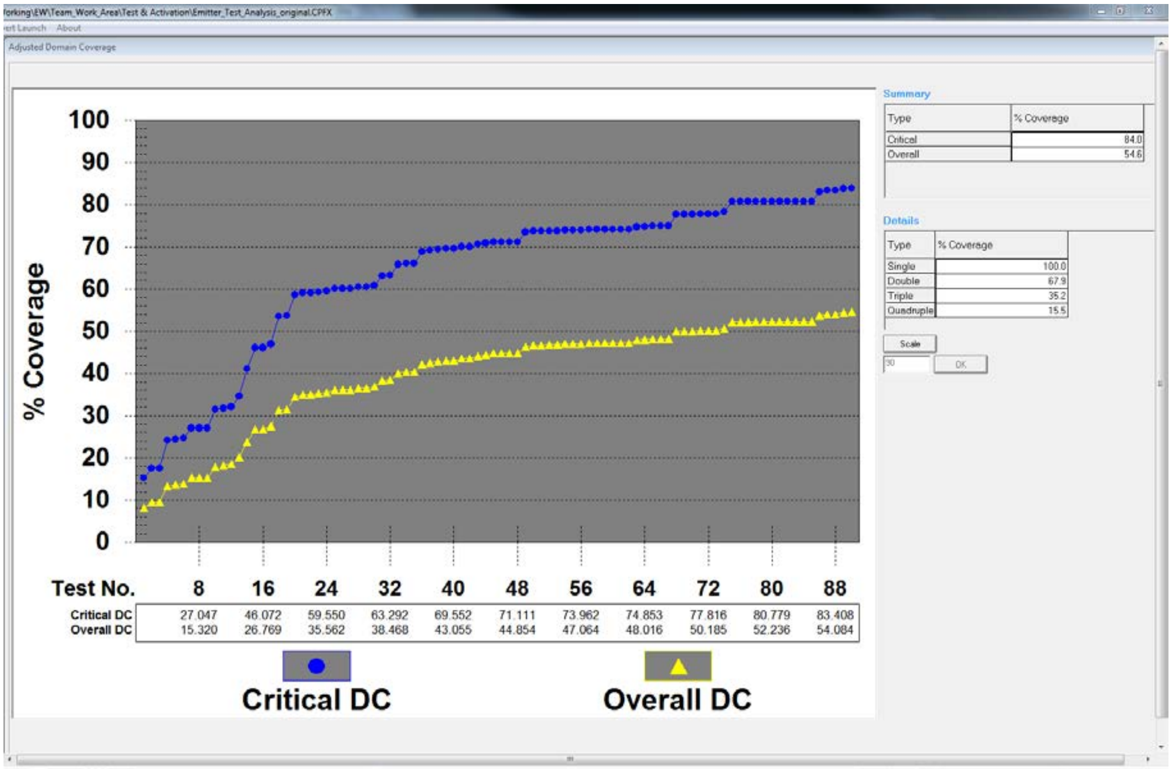

Figure 1: Existing Test Coverage Analysis [9]

Optimized alternative test plan using statistical test optimization using DOE:

Optimized test plan

- 49 test cases proposed (45% reduction)
  - parameter combinations that yield the highest 2-way combinations coverage of the test/capability space, that is, capability-based (tests each parameter class with every other parameter class at least once)
  - improved 3- and 4-way combinations coverage also
  - opportunity for further reduction in number of test cases through exclusion of parameter pairs of lesser value/interest than others (further analysis/consultation required)

Coverage analysis results

- critical coverage: 100% (16% improvement)
- overall coverage: 71.1% (16% improvement)
- 2-way combinations: 100% (32% improvement)
- 3-way combinations: 61.3% (26% improvement)
- 4-way combinations: 23% (7% improvement)
- missing 2-way combinations: 0

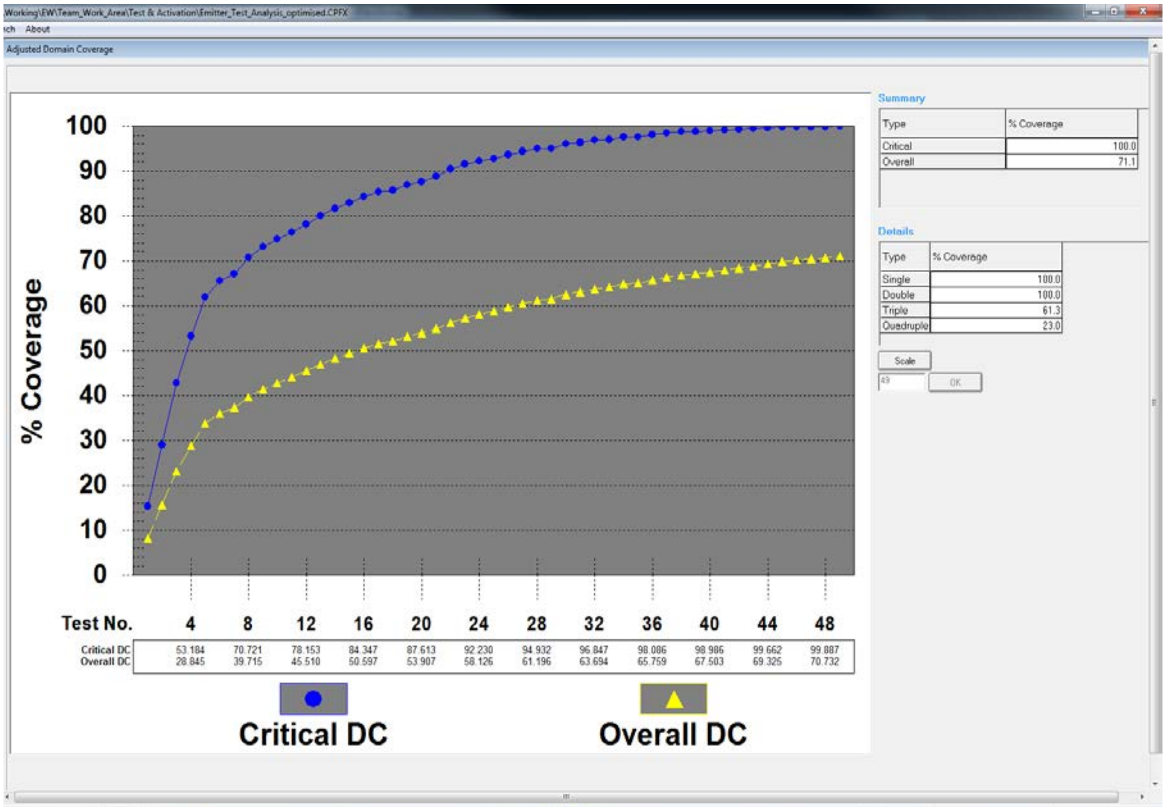

Figure 2: Optimized Test Coverage Analysis [9]

Not only is the optimized plan superior from an efficiency perspective (49 tests versus 90 tests), but also from an n-way coverage perspective. Reinforcing the importance of increased n-way coverage, an industry-wide NIST analysis study across a large number of software STO deployments indicates a strong statistical correlation between improved defect containment and increased n-way test coverage [10].

2.6 Sharing of Best Practices and Lessons Learned

Collaborative sharing across individual programs within Raytheon IDS, Enterprise Raytheon, and the industry is integral to our achieved results to date and our drive for continuous improvement. Below is an affinitized list of our key lessons learned for achieving statistical test optimization high maturity.

Organizational readiness

- STO is a core test planning competency.
- There are development processes for STO practitioners and subject matter experts (SMEs).
- SMEs have an external bias; they are always searching for best practices.
- Trainers and coaches are experienced and motivational.
- STO experts and practitioners are recognized for their results.
- The SME network is well led/networked.
- STO is actively promoted and expected by leadership.
- Success stories are propagated throughout the organization.

- Success is celebrated (“OctoberTest”).
- The organization works to overcome traditional “one factor/requirement at a time” testing mentality.

Process and tools

- Use of scientific test and analysis techniques is integrated directly into the product development process, procedure, and reviews as a part of standard design practice.
- Test readiness reviews focus on evaluating developed test designs, not on whether or not DOE was used.
- STO efforts are integrated rather than run in parallel with traditional methods.
- Recognition exists that process experts tend to underestimate context; domain experts tend to overrate context; the truth is in the middle.
- Test is automated through scripting.
- Be wary of the tendency for statistical tool infatuation (it’s better to be tool agnostic).
- Opportunities for up-front integrated operational analysis, model-based engineering, and Agile application are leveraged.

Program integration

- STO is integral to up-front program planning (“festina lente”).
- A multi-discipline test optimization workshop is provided upfront.
- Implementation is driven by product teams, not by SMEs.
- Analysis output is linked to the risk and opportunity register.
- STO is integral to the test readiness review process.
- Up-front measurement system analysis is in place.
- Integrated and contextual understanding exists of measures of effectiveness (statistical confidence, coverage, and power).
- Be wary of statistical tampering of individual test cases and experimental runs by test leads and operators.
- Test/DOE language issues (test cases, presentations, objectives, missions, scenarios, factors, parameters, etc.) can slow the process and the technical context understanding.

3 Process Performance Modeling and Analysis

This section focuses on the second of three core DFSS methodologies we used to improve our ability to predict and manage our software systems: process performance modeling and analysis.

3.1 Identification of Significant Improvement Opportunity

The Raytheon IDS business and the DFSS team were first exposed to process performance models through the SEI-led development of the CMMI model. Process performance baselines and process performance models are expected CMMI high maturity (maturity levels 4 and 5) artifacts that build on the measurement and analysis activities established at CMMI level 2 to lift an organization from a reactive management state to a proactive management state. By aligning process performance baselines and business objectives, process performance baselines and models act as facilitators to organizational and project success.

Because of their analytical expertise, the DFSS team serves the IDS engineering organization as statistical modeling and analysis SMEs in the development, piloting, deployment, validation, and sustainment of process performance models that align with and enable business success. A suite of developed process performance models (PPMs) have been effectively developed and deployed by Raytheon IDS. Each PPM is identified and selected based on its individual business return to the Raytheon IDS business. The direct relationship between business objectives and quality and process performance objectives, and the use of process performance baselines and models to quantitatively manage our progress toward achieving these objectives, focused our organization on the characteristics of success. If organizational objectives are subjective, the project may become disengaged with those objectives. Making process performance baselines and quality and process performance objectives an integral part of project management clarifies each project's role in business success.

The versatility of the goal question metric (GQM) approach further enabled our development and deployment of PPMs in the form of a goal question *model* approach. As with process performance baselines, all PPM efforts are initiated from the linkage and alignment of quality and process performance objectives and business objectives. This approach is absolutely critical to effective process performance modeling since without this up-front business alignment, there is a tendency to create elegant models rather than effective models that support business objectives.

In this report, the Systems Lifecycle Analysis Model (SLAM) PPM, developed and deployed by Raytheon IDS, is discussed as a representative software systems application case study in order to provide an explanation of the employed methodology and share the lessons learned.

3.2 Methodology Development

Development of our SLAM process performance model was a direct result of a business concern expressed by Raytheon IDS leadership about the productivity and rework risks associated with accelerated concurrent engineering efforts and their potential downstream impact on downstream cost performance. This concern naturally led to our generation of questions around what factors related to our concurrent engineering efforts influence our achievement of cost performance, and

the controllable sub-processes related to those factors. Of specific interest in the development of the SLAM model was the potential statistical relationship between requirements volatility and the degree of requirements/design overlap with that of downstream software development cost performance. Modeling the relationship between potential input factors and project outcomes involved the use of statistical methods such as regression analysis and Monte Carlo simulation.

The resulting SLAM model enables projects with aggressive schedules in which software design activities are planned to begin prior to requirements release are able to quantify the associated cost performance risk, determine the requirements volatility level that must be maintained to meet cost performance objectives, and identify the process changes necessary to manage requirements accordingly.

SLAM Model output and things key stakeholder care about include the following:

- outcome prediction: confidence interval estimation of cost performance (generated using Monte Carlo simulation) utilizing a developed multi-factor regression model
- for key stakeholders, the outcome prediction is of critical importance to them for these reasons:
  - systems/software engineering: enables integrated engineering team risk assessment and sensitivity analysis around the likelihood of achieving cost performance objectives and the development/deployment of mitigation strategies.
  - quality engineering: reinforces the importance of the development and deployment of up-front project quality planning and analysis, paving the way for their value-added involvement

Factors used in the SLAM process performance model include the following:

- requirements volatility
  - post formal requirements document release change %
  - requirements volatility is a required measurement collected and reported by every development project across Raytheon Company
  - organizational/project collected baselines were stratified by product type
  - for simulation input purposes, a Gaussian approximation is typically employed
- requirements/design lifecycle overlap
  - percent of the software/hardware design budget expended (as measured by our earned value management system) at the time of formal requirements document release
  - non-standard project measurement collected and analyzed during the SLAM development piloting and deployment
  - for simulation input purposes, a Gaussian approximation is typically employed

In the specific case of the SLAM model, a mathematical function of the input factors was reasonably well correlated with the output responses using linear regression techniques (with an adjusted r-squared value = 0.65, p = 0.00). See Figure 3 for the graphical portrayal of the data. The regression equation associated with this statistical correlation was the building block for our SLAM model development efforts.

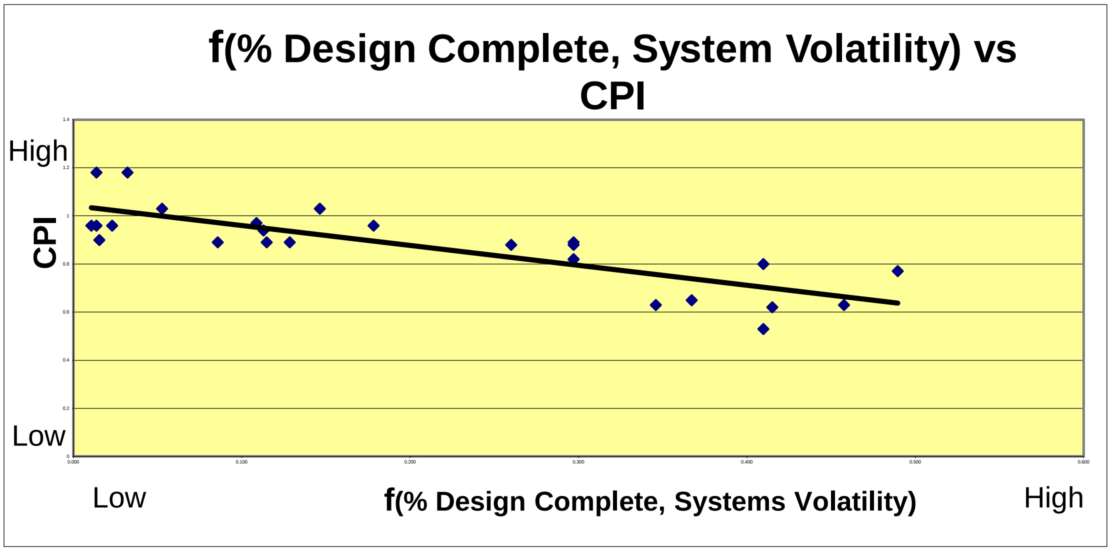

Figure 3: Predictive Model vs. CPI [11]

Healthy ingredients of process performance models as defined by the SEI include the following:

- are statistical, probabilistic, or simulation in nature
- predict interim and/or final project outcomes
- use controllable factors tied to sub-processes to conduct the prediction
- model the variation of factors and understand the prediction range or variation of the outcomes
- enable "what-if" analysis for project planning, dynamic re-planning, and problem resolution during project execution
- connect "upstream" activity with "downstream" activity
- enable project to achieve midcourse corrections to ensure project success

These ingredients have served us well in guiding our process performance model development and deployment efforts. The SLAM model leverages the statistical correlation of controllable factors to an outcome prediction in the form of a regression equation. A user-friendly Excel-based interface was created using industry available COTS tools (either Crystal Ball or @Risk – we have provided an either/or option to enable users with different licensing constraints) to model and statistically generate a cost performance prediction interval using Monte Carlo simulation (see Figure 4).

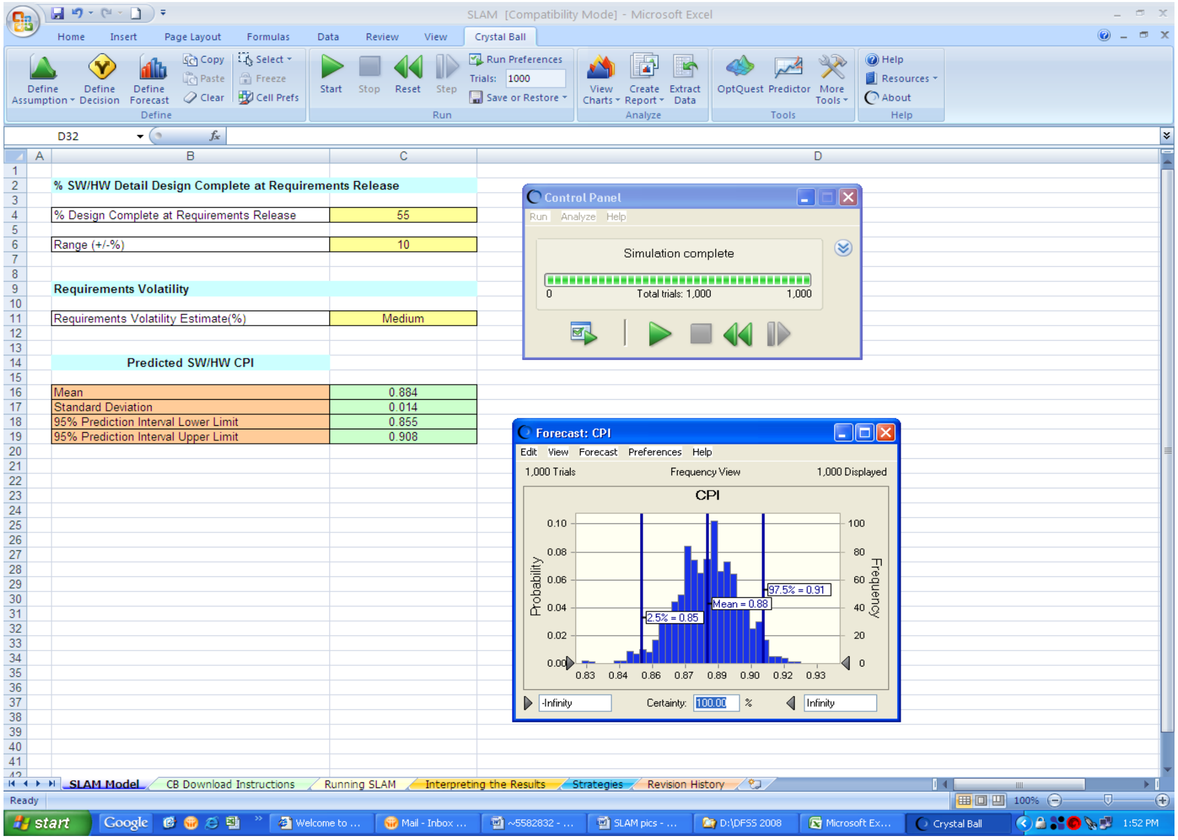

Figure 4: SLAM PPM Model User Interface [11]

Note that the SLAM model user interface also includes worksheets containing Crystal Ball/@Risk download instructions, step-by-step guidance for projects on “Running SLAM” and an “Interpreting the Results” guide.

3.3 Piloting, Measurement, and Refinement

SLAM pilot data collection:

- Requirements volatility
  - a required measurement collected and reported by every development project across Raytheon Company
  - Organizational innovation and deployment (OID) considerations led to initiating the collection of requirements volatility data at the configuration item (CI) or module level to support SLAM piloting.
- Requirements / design lifecycle overlap
  - non-standard project measurement collected and analyzed during the SLAM development piloting and deployment
  - OID considerations led to the SLAM piloting effort working closely with a cross-section sampling of our IDS development projects in defining an objective measurement that is easily collected and readily available.

- Up-front collection-defining dialogue with OID SLAM pilot project teams provided highly valuable analytical and deployment insight.

Specific key takeaways from SLAM piloting

- All stakeholder groups and projects found the SLAM model easy to use and conceptually aligned with project issues.
- The majority of projects identified and implemented specific improvements to the projects' defined process as a direct result of SLAM modeling and analysis including:
  - improving the systems requirements review process and execution
  - increasing the degree of concurrent engineering between systems and software/hardware engineering
  - increased use of critical chain concepts in order to shorten design cycle time
- All projects used SLAM in performing risk assessments.
- Collected project data from SLAM piloting further confirmed the strength of this underlying relationship as defined by the developed regression equation model.

3.4 Integrated Deployment, Validation, and Sustainment

Effective development and deployment of process performance baselines and models have significantly improved upon our process alignment and performance against Raytheon IDS business and engineering objectives. Resulting efforts in the areas of statistical process management, root cause analysis and corrective action, interdependent execution, and statistically-based risk assessment have resulted in increased productivity, reduced rework and improved cost and schedule performance. ROI analysis pertaining to our Raytheon IDS CMMI high maturity efforts has indicated a 24:1 return from our process investment. Process performance baselines and models are the spark that ignited these results and fuels our drive for more.

Specific key takeaways from SLAM deployment, validation, and sustainment

- Engineering process group (EPG) process funding was invested in the development and deployment of the SLAM Model with an estimated improvement of 5.5% – 11.5% for software development CPI (dependent on established requirements volatility baseline).
- Based on its deployment results, SLAM has been formally integrated into our development process; accordingly, SLAM was formally released to the Raytheon Process Assets Library (RPAL).
- In addition to deployed results, SLAM data was cited by the IDS Software Engineering Director during schedule negotiations with program management.
- SLAM usage is documented in the IDS Engineering Standards, Engineering Measurement and Analysis Plan and supporting templates.
- Additional process funding is set aside for maintaining and updating the SLAM tool and supporting its continued project deployment.
- With one exception (believed to have data integrity issues), all projects found model predictions to be aligned with project actuals.

3.5 Sharing of Best Practices and Lessons Learned

Integral to the process performance modeling deployment process is the collection of specific (to the individual model, in this case SLAM) and general best practices and lessons learned.

Specific SLAM lessons learned (in terms of mitigation strategies):

SLAM lessons learned for reducing requirements volatility and its effects on project performance

- Improve requirements reviews.
- Increase the degree of concurrent engineering between systems and hardware/software.
- Increase understanding of the customer value equation.
- Add more experienced personnel to the team.
- Improve team communications.
- Provide for increased coaching and mentoring.

SLAM lessons learned for reducing the degree of overlap

- Create increased awareness relative to the involved risks
- Release earlier, followed by successive implementation iterations.
- Delay detailed design efforts.
- Use techniques such as critical chain to shorten development cycle time by reducing the waste and running in parallel where non-critical.
- Release even later, but with exceptional quality (low volatility) in order to reduce churn and rework driving up cost.

General PPM best practices and lessons learned (in terms of challenges) include the following:

- identifying the correct x factors to model
- obtaining sufficient and meaningful data
- verifying data quality and integrity
- initial project team engagement
  - All engineering disciplines need to be present with their project plans/data at the deployment meeting in order to produce the best results (for effective dialogue and brainstorming and recognition of interdependence).
- internal Crystal Ball and @Risk download issues
- Some users entered in data beyond the range used to calibrate the model. Model was updated to caution users.
- documenting evidence of use of models

The effective development and deployment of the process PPMs has sparked increased Raytheon IDS interest in the following:

- interdependent, integrated business execution
- statistically-based project performance risk assessment
- identification of leading indicators that statistically drive project performance

- statistical modeling and analysis supporting tools and training
- follow-on statistical modeling and analysis efforts
- business investment in process performance modeling throughout the product development lifecycle

4 Cost and Schedule Risk Analysis Using Monte Carlo Simulation

In this section, we explain our use of cost and schedule risk analysis using Monte Carlo simulation, the final of the three core DFSS methodologies described in this report.

4.1 Identification of Significant Improvement Opportunity

Given increased industry competition and heightened customer expectations in the form of lower costs and shortened delivery cycle time, it is more critical than ever that we understand the uncertainty associated with cost estimation and scheduling to ensure successful execution and proactive risk and opportunity management.

As stated in a recent SEI technical report, "Difficulties with accurately estimating the costs of developing new systems have been well documented, and cost overruns in new systems development are well known. The headline of a recent defense magazine article referred to the true cost of a weapon as 'anyone's guess,' reflecting this widely acknowledged fact."[4] Not to be outdone by the challenges in cost estimation, there may be no more daunting challenge than that of schedule pressure. Countless jobs are falling under the category of "Yes we can do it, but not with that schedule!"

A number of qualitative factors further exacerbate the industry cost estimation and schedule planning problems, including the following:

- need for cost estimates driven earlier and earlier in the acquisition lifecycle before a technical baseline is established
- increasing, competitive pressure to be aggressive enabling some individual task activity estimators to become overly optimistic in their assumptions (half-full perspective)
- conservative estimation by some individual task activity estimators based on their fear that management will make some cuts (half-empty perspective)
- without estimated ranges around each of the individual task activity estimates, it is difficult for management or reviewers to identify which estimators are being aggressive and which are being conservative without playing a game of 20 questions and conducting a thorough examination of the supporting historical data set

Use of cost risk analysis (CRA) and schedule risk analysis (SRA) with Monte Carlo simulation complements and greatly improves upon traditional deterministic methods in quantitatively assessing the risk and opportunity associated with cost estimation and schedule planning, enabling increased sensitivity, trade space analysis, and implementation of strategies for cost risk mitigation and opportunity capture.

4.2 Methodology Development

Monte Carlo simulation is used to perform risk analysis by building a mathematical model based on the substitution of a range of values (in the form of a probability distribution) instead of a point

estimate for any parameter that has inherent uncertainty. In short, Monte Carlo simulation recognizes that there is uncertainty around each of our estimated parameters and takes it into account. Historical actuals as well as information relative to the context being estimated (similar to product actuals, product reuse, etc.) are used to estimate the range or distribution for cost for each work product. The rationale is recorded for each estimated range to ensure that we are objectively capturing the basis behind each of these estimated ranges. Typically, because of its ease of use and flexibility, the triangular distribution is used with three inputs: low (5^{th} and 1^{st} percentile), most likely, and high (95^{th} and 99^{th} percentile). The triangular distribution is highly flexible because it can be easily skewed to mimic the form of almost any distribution. Once each input parameter has been estimated, a histogram is generated of the statistical probability distribution of predicted total cost/effort for selected confidence levels through the statistical random drawing (typically of the order of 1,000 SRA and 10,000 CRA data points) from each of the underlying sub-product distributions. Monte Carlo simulation output analysis also provides valuable practical insight into the key drivers of cost and schedule variability and enable sensitivity analysis.

Cost and schedule risk analysis using Monte Carlo simulation has the following benefits:

- leverages existing historical actuals, similar-to data, engineering insight, and Monte Carlo simulation
- enables projects to statistically estimate cost and schedule, quantify the risk and opportunity associated with meeting cost and schedule targets, identify cost and schedule drivers, and perform sensitivity analysis
- enables non-binding budgetary estimate (NBBE) and schedule "what if" scenario analyses

Inputs to the simulation include the following:

- fully-networked schedule (integrated master schedule) which has been validated as a robust, predictive model
- cost estimates for tasks in the format of three-point estimates
- schedule durations estimated for select tasks and high-risk areas using three-point estimates
- probability distributions assigned (the triangular distribution is typically employed because of its robustness)
- rationale required for selection of distribution parameters

Outputs include the following:

- probability distributions (histograms) of predicted overall cost, overall schedule, and specific schedule milestones
- predicted overall cost and schedule for selected statistical confidence levels
- identification of statistical drivers enabling sensitivity/risk analysis

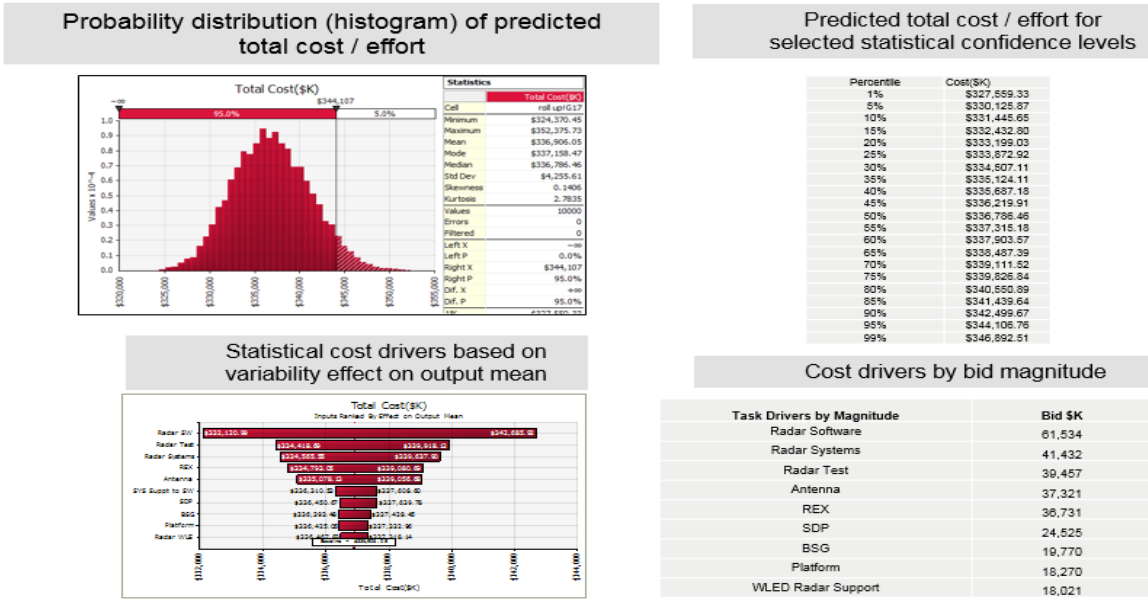

Figure 5: Example Cost Risk Analysis (CRA) Output

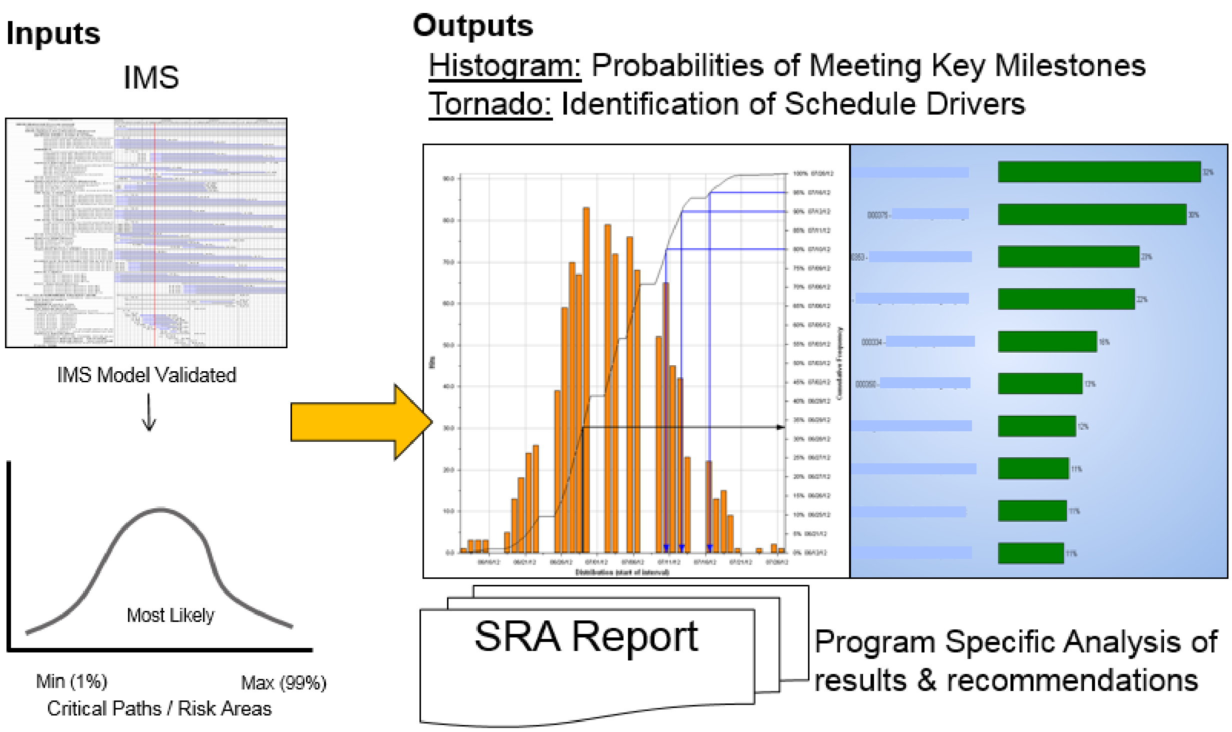

Figure 6: Example Schedule Risk Analysis (SRA) Output

4.3 Piloting, Measurement, and Refinement

Piloting a new CRA model and a revamped SRA execution model was instrumental in the maturation of these processes. Piloting demonstrated the value and helped to get buy-in from leadership and end-users before more widespread deployment.

Key piloting takeaways:

- Stakeholder groups and projects found CRA and SRA models both easy to use and conceptually aligned with project issues.
- Providing subject matter experts (SMEs) to facilitate the CRA and SRA processes with teams aided adoption and change management
- Projects identified and implemented specific improvements to their processes and their execution as a direct result of CRA and SRA piloting that enabled cost and cycle time reductions and proactive risk and opportunity management, including:
  - process redesign based on critical path dependency
  - resource reallocation and conflict resolution
  - increased investment up front in planning, analysis, and training activities in order to enable execution speed (“festina lente”)
  - minimized churn through enhanced peer review
  - provided increased quantitative understanding of overall cost and schedule estimation risk and opportunity and associated statistical drivers enabling prioritization and cost/risk-benefit evaluation of cost/schedule optimization action plans
  - in addition to deployed projects, SRA has been used up-front during the bid and proposal phase and is used by leadership to develop negotiation strategies and shape contractual terms and conditions

4.4 Integrated Deployment, Validation, and Sustainment

After successful pilots and organic, bottom-up growth, CRAs and SRAs became integrated into standard business practices through senior leadership buy-in and top-down requirement modifications. SRAs are required for all programs with the exception of non-schedule driven efforts, and CRAs are required for development proposal engineering reviews, Systems Architecture Design and Integration Directorate (SADID) functional reviews, and System Validation Test and Analysis Directorate (SVTAD) functional reviews, and they are recommended for other functional areas.

Key transition-to-sustainment takeaways

- Finance process funding was invested in the development and deployment of the revamped schedule risk analysis model.
- Engineering process funding was invested in the development and deployment of the new cost risk analysis model.
- The deployment of cost risk analysis has resulted in increased proposal efficiency and speed in development of proposals.

- The deployment of schedule risk analysis has resulted in an objective understanding of schedule risks, opportunities, and sensitivity drivers, thus enabling data-driven decision-making and action plans.
- Coupled with a price-to-win confidence interval developed in parallel, CRA output has enabled Raytheon IDS leadership to make decisions about competitive pricing alternatives and their associated risk and opportunity.
- CRAs have been formally and fully integrated into our product development and engineering review processes.
- SRAs have been formally and fully integrated into leadership program reviews and program management plans.
- Additional process funding is set aside for maintaining and updating the supporting CRA and SRA tool sets and supporting continued project deployment.

4.5 Sharing Best Practices and Lessons Learned

As CRAs and SRAs matured, it was essential to continuously improve and leverage best practices and lessons learned and facilitate knowledge sharing across the business. The CRA and SRA technical element owners leveraged their functional organizations (engineering and finance, respectively), the DFSS organization, and other communication and collaboration forums such as communities of practice, business-level and enterprise-level councils, and other partnerships— both internal and external to Raytheon.

Key lessons learned

- Alignment across all levels of the business on the vision, skills, incentives, resources, and action plans is required to roll out new processes.
- Deployment of new processes via a centralized SME model drives consistency and quality, accelerates learning, and fosters change management.
- SMEs provide an objective, independent perspective unaffected by project politics or culture and highlight risks and opportunities that are easily overlooked by those too close to the initiative.
- A focus on business value and providing objective, data-driven, actionable recommendations and insights is necessary.
- Use readily available commercial-off-the-shelf (COTS) simulation tools, such as @Risk, Crystal Ball, and Primavera Risk Analysis.

5 Summary: Enabling Integrated Project Team Performance Using Design for Six Sigma

5.1 Bringing It All Together in an Integrated Project Plan

The Raytheon IDS engineering DFSS team was formed to identify, develop, pilot, and deploy industry best practice product optimization methods and processes to predict, manage, and improve performance, producibility, and affordability for the benefit of our customers. Accordingly, the effectiveness of the IDS DFSS program is largely dependent on our ability to enable individual project team performance.

Integral to the product development effort is the Integrated Product Development System (IPDS) developed by Raytheon Enterprise. IPDS is a system of enterprise-common processes, process-related assets and enablers, reference and training materials, deployment materials, and support services that enable repeatable and efficient program capture, planning, and execution. At the heart of this system is the IPDP, which is a collection of common, tailorable, multi-discipline processes applied across all businesses describing what information must be captured to execute product development, production, and support programs. As stated by Mark Russell, Raytheon Vice President of Engineering, Technology, and Mission Assurance, "The Integrated Product Development Process eliminates doubt and provides more predictable program results, therefore allowing our employees to focus their creativity where it belongs—on innovating solutions for our customers."

As one would imagine, approval for the inclusion of a developed process and enablers in IPDS requires rigorous proof that the development methodology is technically sound in principle and has been effectively piloted and delivered performance results to project teams. Once a developed DFSS process and its set of supporting enablers has been successfully piloted they are included in IPDS, moving them from best practice to standard practice. And since the DFSS team is always in the process of identifying, developing, piloting, and deploying best practices to enable our projects, there is, in effect, always a pipeline of DFSS processes and methods that we are looking to move from best practice to standard practice. Accordingly at program kickoff, each integrated project team builds a “go forward” project plan using IPDS and tailoring it to fit their context. As with any other element of IPDS, DFSS-developed standard processes/methods are included in this tailoring.

5.2 In-process Validation of Achieved Execution Results Against Plan and Refinement

The DFSS team supports this integrated project planning effort, providing key subject matter expertise, training, and tools as needed to enable the DFSS integration into the project plan and for defining expectations and delivering results against that expectation. In order to assure that the execution by the integrated project team aligns with the developed project plan, independent reviews are integral to all project lifecycle gate reviews. The results achieved from the integrated DFSS

program deployments are then analyzed against expectations and used to update historical baselines and prediction models. The finance organization signs off on any calculations of achieved financial savings to ensure business and program impact.

5.3 Cross-project Sharing of Best Practices and Lessons Learned

Cross-project, cross-Raytheon, and cross-industry sharing of best practices and lessons learned is integral to the success of the DFSS program and to our efforts for continuous improvement. The ability to effectively share and collaborate across organization boundaries is considered a business competitive advantage integral to the way we are organized, the way we share, and the way our sharing success is measured.

Toward this end, the DFSS team is a multi-functional team that reports at the engineering level as part of engineering strategic process (not at the systems or software organizational level), and is comprised of core team members from each of the Raytheon engineering disciplines: System Architecture, Design and Integration Directorate (SADID), System Verification, Test and Analysis Directorate (SVTAD), Software Engineering Directorate (SED), Electrical Design Directorate (EDD), Mechanical Engineering Directorate (MED), and Whole Life Engineering Directorate (WLED) (which includes reliability, affordability, maintainability, and so forth).

Enterprise-wide communities of practice (CoP) also enable us to share best practices and lessons learned across IDS projects and the Raytheon Company as a whole. CoPs are focused groups of SMEs from across Raytheon that get together regularly to advance a specific field of study and share best practices and lessons learned across the company. The DFSS team has initiated and currently leads a number of DFSS-related CoPs, related to such activities as statistical test optimization, system cost modeling, and analysis using Monte Carlo simulation. The DFSS team is also an active participant in the schedule RAACE CoP. All Raytheon DFSS projects are tracked through to completion and updated accordingly as new data in the form of actuals, lessons learned, and so forth that can be obtained in our DFSS database management system.

Complementing these collaborative sharing efforts within the company, the Raytheon DFSS team actively participates in, presents at, and leads industry conferences, symposiums, workshops, and forums related to product development optimization. The number of strategic industry technical presentations and collaborative knowledge sharing events led by or participated in by the IDS DFSS team is tracked against a developed annual goal as a measure of our degree of external engagement, which is a mechanism for further enabling our quest for identifying potential future best practices, leveraging lessons learned, and avoiding pitfalls experienced by others.

Appendix Acronym List

C5I	command, control, communications, computing, cyber, and intelligence
CDM	combinatorial design methods
CMMI	Capability Maturity Model Integrated
CoP	communities of practice
DFMA	Design for Manufacture and Assembly
DoD	Department of Defense
DOE	Design of Experiments
CI	configuration item
COTS	commercial-off-the-shelf
CPI	cost performance index
CRA	cost risk analysis
CW	continuous wave
DFSS	Design for Six Sigma
EED	Electrical Design Directorate
EPG	engineering process group
EW	electronic warfare
GQM	goal question metric
IPDP	Integrated Product Development Process
IPDS	Integrated Product Development System
IDS	Integrated Defense Systems
M&A	measurement and analysis
MED	Mechanical Engineering Directorate
NBBE	non-binding budgetary estimate
NIST	National Institute of Standards and Technology
OID	organizational innovation and deployment
OPM	Oregon Productivity Matrix

PPM	process performance model
QUELCE	Quantifying Uncertainty in Early Lifecycle Cost Estimation
RAACE	risk assessment and critical chain for execution
RPAL	Raytheon process assets library
SADID	System Architecture, Design, and Integration Directorate
SED	Software Engineering Directorate
SLAM	Systems Lifecycle Analysis Model
SRA	schedule risk analysis
SVTAD	System Verification, Test, and Analysis Directorate
STO	statistical test optimization
WLED	Whole Life Engineering Directorate

Bibliography

URLs are valid as of the publication date of this document.

[1] M. Campo and N. Mackertich, “Goal-Question-Model,” presented at the NDIA CMMI Technology Conference and User Group, Nov. 2009.

[2] D. Cleotelis and N. Mackertich, “How do we win this game when the rules keep changing? A case for the increased application of Design for Six Sigma in systems engineering,” *INCOSE International Symposium*, vol. 16, pp. 91–103, Jul. 2006.

[3] M. Chrissis, M. Konrad, and S. Shrum, *CMMI for Development*, 3rd ed., Addison Wesley, 2011.

[4] R. Ferguson, D. Goldenson, J. McCurley, R. Stoddard, D. Zubrow, and D. Anderson, *Quantifying Uncertainty in Early Lifecycle Cost Estimation (QUELCE)*, Software Engineering Institute, Carnegie Mellon University, Pittsburgh, Pennsylvania, Technical Report CMU/SEI-2011-TR-026, 2011. http://resources.sei.cmu.edu/library/asset-view.cfm?AssetID=10039

[5] R. Fisher, *The Design of Experiments*, 9th ed., MacMillan, 1971.

[6] L. Freeman, G. Hutto, and N. Mackertich, “Scientific methods for improving DoD test and evaluation,” *ITEA Journal*, vol. 35, no. 1, pp. 31-39, Mar. 2014.

[7] J. Gilmore, “Guidance on the use of Design of Experiments (DOE) in operational test and evaluation”, memorandum from Operational Test and Evaluation, Office of the Secretary of Defense, Oct. 19, 2010.

[8] M. Gladwell, “Malcolm Gladwell on spaghetti sauce,” TED Talk, 2004, http://www.ted.com/talks/lang/eng/malcolm_gladwell_on_spaghetti_sauce.html

[9] P. Kraus and N. Mackertich, “Statistical test optimization high maturity best practices and lessons learned,” presented at the NDIA Test and Evaluation Conference, Mar. 2016.

[10] D. Kuhn, D. Wallace, and A. Gallo, "Software fault interactions and implications for software testing", *IEEE Trans. Softw. Eng.*, vol. 30, no. 6, Jun. 2004.

[11] N. Mackertich, M. Campo, and R. Beitz, “System Lifecycle Analysis Model (SLAM),” presented at the SEI High Maturity Measurement and Analysis Workshop, Nov. 2008.

[12] N. Mackertich and M. Campo, “Scheduling Analysis of Variability Engine (SAVE) Model,” presented at the SEI High Maturity Measurement and Analysis Workshop, Mar. 2009.

[13] N. Mackertich, K. Mittelstaedt, and K. Grimes, “Statistical performance, cost, and schedule risk analysis,” presented at the SEI High Maturity Measurement and Analysis Workshop, May 2014.

[14] D. Montgomery, *Design and Analysis of Experiments*, 8th ed, Wiley and Sons, 2012.

[15] R. Myers, D. Montgomery, and C. Anderson-Cook, *Response Surface Methodology: Process and Product Optimization Using Designed Experiments,* 3rd ed., Wiley and Sons, 2009.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave Blank)	2. REPORT DATE April 2017	3. REPORT TYPE AND DATES COVERED Final
4. TITLE AND SUBTITLE IEEE Computer Society/Software Engineering Institute Watts S. Humphrey Software Process Achievement Award 2016: Raytheon Integrated Defense Systems Design for Six Sigma Team		5. FUNDING NUMBERS FA8721-05-C-0003
6. AUTHOR(S) Mackertich, Neal; Kraus, Peter; Mittelstaedt. Kurt; Foley, Brian; Bardsley, Dan; Grimes, Kelli; and Nolan, Mike		
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Software Engineering Institute Carnegie Mellon University Pittsburgh, PA 15213		8. PERFORMING ORGANIZATION REPORT NUMBER CMU/SEI-2017-TR-001
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) AFLCMC/PZE/Hanscom Enterprise Acquisition Division 20 Schilling Circle Building 1305 Hanscom AFB, MA 01731-2116		10. SPONSORING/MONITORING AGENCY REPORT NUMBER n/a
11. SUPPLEMENTARY NOTES		
12A DISTRIBUTION/AVAILABILITY STATEMENT Unclassified/Unlimited, DTIC, NTIS		12B DISTRIBUTION CODE
13. ABSTRACT (MAXIMUM 200 WORDS) Design for Six Sigma (DFSS) is an industry recognized methodology used by Raytheon's Integrated Product Development System to predict, manage, and improve software-intensive system performance, producibility, and affordability. The Raytheon Integrated Defense Systems DFSS team has developed and implemented numerous leading-edge improvement and optimization methodologies resulting in significant business results. These achievements have been recognized by the Software Engineering Institute and the Institute of Electrical and Electronics Engineers with the 2016 Watts Humphrey Software Process Achievement Award. Best practice approaches used by the team are shared in this report, including the generation of highly effective and efficient test cases using Design of Experiments, process performance modeling and analysis, and cost and schedule risk analysis using Monte Carlo simulation.		
14. SUBJECT TERMS Software, performance, optimization, modeling, simulation, IEEE/SEI SPA award		15. NUMBER OF PAGES 38
16. PRICE CODE		

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89) Prescribed by ANSI Std. Z39-18
298-102